Wireless Sensor Networks: State of the Art and Future Perspective

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Abstract

To reduce labour costs, the responsibilities of greenhouse production managers are ever increasing. This makes the decision-making process more complex and more information from the greenhouse work floor is needed. There is a tendency towards monitoring and managing crop production at plant level instead of monitoring the whole greenhouse, and as such there is an increasing amount of information coming from smaller individual sub-systems. To gather this information, Wireless Sensor Networks (WSN) are beginning to play an important role. A few years ago, WSN entered the agricultural and horticultural domain. Advantages of WSN over wired sensors are: lower installation costs, flexibility and mobility. This paper presents a survey of the state of the art of WSN. The technical requirements of WSN in greenhouse crop production will be discussed. A WSN with 100 nodes to measure differences in spatial temperature and humidity is being used in a research project of Wageningen UR Greenhouse Horticulture. The preliminary results of this project are shown in this paper.

INTRODUCTION

In the early 70s the first mobile phones were demonstrated by the American companies Motorola and AT&T. At first people were slow to pick up this new technology. Once the devices became small enough, had sufficient battery life and dense networks were installed by telephone companies, the market rocketed. One of the reasons of the success of mobile phones is that it solves a problem in communication between humans. With mobile phones people have the freedom to communicate where they want, with whoever they want, in most places. Nowadays wireless technology is also frequently used in communication between people and devices. In addition to mobile phones, other means of wireless communication such as Wifi and Bluetooth, help people to communicate with devices or between devices and are rapidly becoming more widely used (Wang et al., 2005).

In the near future it is foreseen that all our everyday appliances and objects will be fitted with a wireless communication device embedded with a sensor and a small energy source (Fig. 1). This technology is called Wireless Sensor Networks (WSN) or ‘smart dust’. These are made up of small nodes that are able to transfer sensor data or other information to a central point. To make this happen, the technology must be very cheap (less than one dollar per node), very small (less that 1-2 mm^3), reliable, self organizing and fault tolerant and it should need very little power and no maintenance. The market potential is enormous and a lot of research and development effort has been put into this area.

Doing business in an increasing competitive environment where different processes are interconnected and less employees have to supervise larger production areas, will require that we gather accurate information quickly and cheaply. In the future, WSN will play an important role in horticulture. For example in areas where electrical power is not available all the time, WSN can replace normal sensors which rely on a power cable. Because of their small size and relatively low cost, it is now possible to conduct research in temperature distribution or the spreading of diseases in greenhouses, using dense WSN. In this paper the results from a literature review are discussed and are used to give a current state of the art of WSN, which will be related to future developments expected of WSN in horticulture. A full scale experiment with a WSN in a greenhouse with 100 sensor nodes at a cucumber grower in the Netherlands will be described.

When we search literature databases, using the keywords “wireless sensor networks”, a large number of hits are registered. But when the same keywords are combined with “agriculture” or “horticulture” the number of results plummets to a few hits (Table 1). When we cross compare these results, the difference is largely explained due to the gap between a lot of theoretically scientific work that has been conducted in WSN and the small number of WSN that has been deployed in (horticultural) situations. Greenhouse climate and crop production can be controlled more accurately at a small scale if the right tools, in terms of sensors and actuators, are available. Therefore, WSN manufacturers, engineers and scientists will play an important role to successful integrate WSN into daily horticultural practice.

WSN manufacturers, many of which are working in cooperation under the Zigbee Alliance (www.zigbee.org), are today building components for WSN that are half way between what is foreseen for the future and what is feasible in production today. When one wants to build a WSN application with this currently available technology, one has to adapt it to the demands and constraints of the desired practical application. This is usually more difficult than it seems (Visser et al., 2006; Tateson et al., 2005; Minami et al., 2005). The results from the literature review indicate that a lot of research is still going on, and many issues are still not resolved. Some practical experiments (Zhu et al., 2006; Tateson et al., 2005) show that most WSN are not reliable enough, they can’t withstand outdoor climate conditions, lose communication, are not fault tolerant, use too much power, are damaged too quickly and are riddled with new problems not foreseen by manufacturers or end users. One of the biggest problems of dense WSN are the initial cost (nowadays between €100 and €350 per sensor node), short communication distances (10-30 meter) and the maintenance cost to replacing batteries too frequently (Visser et al., 2006).

INDUSTRIAL DEVELOPMENT, STANDARDIZATION AND THEIR IMPACT ON HORTICULTURE

Here we briefly review WSN in horticultural applications. The Zigbee alliance is working towards a standardization of all the key components of a WSN node and network protocols (Baronti et al., 2007). The Zigbee alliance set goals for the future to ensure that current developments in research and engineering will help to overcome the obstacles mentioned above. The standardization of the broadcast frequency of WSN at 2.4 GHz is one example where future problems for horticulture practice may arise. This frequency is absorbed by water rich objects (like plants) which will likely shorten the distance at which nodes can communicate with each other. This will likely make any applications built with Zigbee protocols and hardware more difficult for horticultural applications.

Communication

A WSN consists of nodes that are able to communicate wireless with each other or to a central point (sink node). In most WSN, communication is made possible by a low power radio chip and antenna. Other means of inter-node communication are given by Baronti et al. (2007) and Akyildiz et al. (2002). The sink node is a base station that receives the packets of data from individual nodes. It is usually connected to a computer or the internet, by which data are ultimately stored in a database. The data is then analyzed presented in graphs and/or tables, and end users then have the ability to take decisions.

WSN Types in Horticultural Practice

If a node is equipped with a powerful enough radio the node directly communicates with the sink node, this is called a star type network (Fig. 1). For this type of network directional antennas are mostly used. In a greenhouse, a star network can be used when the nodes are fixed in position. This is applicable for WSN measuring temperature, CO_2 levels or humidity levels in crops that are not moved around like tomatoes or sweet peppers. The preferred direction of radio propagation of the directional antenna is pointed at the sink node so that for the same amount of power, radio signals can be transmitted a longer distance from node to sink node. The communication distance of a node is limited primarily by energy constraints (Baronti et al., 2007; Akyildiz et al., 2002). Nodes which cannot communicate directly to a sink node can route their data via other nodes towards a base station. This type of network is called a mesh network (Fig. 1). The routing of data from node to node is called hopping. This type of network can be used when the node is attached to movable parts such as containerized plants, harvested fruit and vegetables, transportation vehicles or human labourers.

WSN Microchips

The flow control of messages, the gathering of data, network deployment and power management are controlled by software which resides on a microchip. Most microchips have an analogue to digital converter (ADC) or digital input and output (IO) ports available (Fig. 1). These are used to attach sensors to almost any sensor with an analogue or digital output which is used to gather the specific information.

WSN Software in Horticultural Practice

One of the more popular languages to build software applications for WSN is called TinyOs (www.tinyos.org). It is an operating system for small applications that run on WSN-nodes. The software handles many tasks, some of which are: the translation of sensor data into digital information, basic arithmetic, decision-making based upon sensor information, etc. An excellent review and examples of the vital role of software are given by Cox (2002) and Minami et al. (2005). In horticulture, WSN software can help the grower to make better decisions. For example, growers with many different clients who have different product needs may need tomatoes at different stages of ripeness. Historical greenhouse climate data from a dense WSN can show from which part of the greenhouse the most ripe tomatoes, or ones with long shelf life can be harvested. If the labourers are equipped with a WSN transceiver the decision support system can guide the labourer to the location where the desired tomatoes are. Another example of good use of software is ambiguous computing by using a WSN. A good example is given by Beaulah et al. (1998) where sensor information of a wired sensor network is verified and used to compute when sensors are giving false information, or if indeed alarming situations are happening in a greenhouse climate.

Energy Sources

Nodes in a WSN require energy to run the microcontroller and the sensor. Although WSNs are designed with low power consumption in mind, batteries will eventually run out of energy. The following strategies can be followed in horticulture when dealing with this obstacle. In the first scenario, batteries and nodes are so cheap it is more cost effective to throw them away than to replace the batteries. This is more for future inexpensive WSN nodes, but it also creates undesired waste. Secondly, the batteries can be changed or recharged at the end of a growing cycle. The costs will have to balance against the extra savings made using a WSN. Three, WSN nodes could harvest their own energy from sunlight via photovoltaic cells. Although this technology is still expensive, it has been shown to be feasible (Minami et al., 2005). Many energy saving routines and strategies have been reviewed by Baronti et al. (2006) Minami et al. (2005) and Akyildiz et al. (2002).

Packaging and Practical Demands for a WSN in Horticulture

The packaging of a WSN node is not as trivial as it seems. In greenhouse applications it would have to cope with a harsh climate (for electronics). Most plastics can not withstand the high solar radiation combined with high relative humidity (RH) levels. A sensor has to be protected from this environment and especially T and RH sensors from direct solar radiation, since direct radiation will give erroneous temperature readings. However, enclosing the sensor too closely cause problems because it increases the distance between the sensor and the environment that has to be measured precisely. The following list gives an idea of more practical problems when dealing with WSN in horticulture:

- Nodes can be moved to an undesired location if they are attached to plants;
- Nodes can get soiled / oxidized and give false sensor readings;
- Nodes can get lost or entangled in the crop;
- Nodes can end up in the supply chain or with customers;
- Plants will grow larger, this will influence the climate and the way how the climate data from a WSN should be interpreted;
- Larger plants represent a larger volume of water, this can negatively influence radio wave propagation and shorten communication distances;
- Most alkaline batteries operate up to 45-50°C: in direct sunlight these temperatures are rapidly reached within enclosed packages and can permanently damage the battery;
- If radio contact is lost or if too many data packages get lost during transmission, the quality / integrity of the data may be significantly reduced.

EXPERIMENT, MEASURING THE TEMPERATURE DISTRIBUTION IN A GREENHOUSE BY USING A WSN WITH 100 NODES

Occurrence of diseases, growth and yield differences may be linked to differences in temperature and humidity throughout the greenhouse. Therefore it is important to measure the temperature distribution in a greenhouse to locate cold and hot spots, over time. This knowledge might be used to setup new heating or ventilation strategies which might lead to energy savings or a higher production. In the past the temperature distribution was estimated by using CFD models. Verifying these models on a large scale was very difficult and very costly, since one had to install many cabled sensors to conduct the experiment. A WSN is an excellent tool for doing these kinds of experiments. The installation time of 100 nodes in this experiment was 12 hours.

Materials and Methods

Our goal was to install 100 nodes, to measure the T between 0 and 50°C and RH between 20 and 100% at one-minute intervals. The nodes had to be able to withstand a greenhouse climate and communicate over a distance of 100 meters so that a greenhouse of more that one hectare could be covered. An off-the-shelf WSN called Wisensys (www.wisensys.com) was chosen which fulfilled our specifications (Fig. 2). This particular system had the following properties: a communication distance of 1000 m direct line-of-sight, a 3-year battery life, a T and RH sensor from Sensirion (www.sensirion.com) that meets our requirements (as stated above) and a greenhouse-proof packaging for most of the electronics.

Results

The Wisensys system was tested in two stages. First, the accuracy of the sensor was compared to other calibrated sensors in a growth chamber (Fig. 2). Figure 3 shows the results of this test at which the line “wy1” indicates that during the marked period, the temperature given by the Wisensys node was 1 to 1.5°C higher than the average dry wet bulb measurement. At that time the lighting of the growth chamber was turned on at full intensity (120W•m^{-2}). It was concluded that direct radiation from light sources influenced the T and RH sensor too much. To overcome this problem a radiation cover, a white plastic rectangular plate, was installed above the sensor and the experiment was run a second time (Fig. 3, right). The average deviation was less than 0.3°C, this showed that the cover helped to reduce the influence of direct solar radiation on the sensor. In a second test the communication distance was tested in a greenhouse in which tomatoes were grown. In this test the nodes were placed at varying distances throughout the greenhouse (Fig. 4). The results were somewhat mixed, nodes in line of sight at 75 meter (such as number 6) yielded only 31% of successfully transmitted data packages. In contrast number 11 at 65 meter had 90% successful data transmissions with no line of sight. From this experiment it cannot be concluded why this occurs but similar results were found by Tateson et al. (2005) and Minami et al. (2005). Further research on this issue is required. Finally, the WSN was installed in a cucumber greenhouse, measuring 90 m by 170 m (Fig. 5). The nodes were hung 0.3 m below the cultivation wire at a height of 1.8m. Data were logged from each of the 100 nodes every minute. Only two out of the 100 nodes installed did not achieve connectivity with the base station, for reasons that are still under investigation. The base station is connected to a personal computer with internet access. The WSN data are accessible via the internet and MATLAB software was used to make a temperature contour plot (Fig. 5).

Future Plans

The results (Fig. 5) show that it is technically feasible to deploy a WSN in a greenhouse and get satisfactory results. Until the end of 2007, the results of this study will be verified and the experiment repeated to test if the outcomes are indeed correct. The results will be used to test new strategies in climate control and to validate greenhouse models.

CONCLUSIONS

Results from this literature review show that the practical use of WSN in horticulture is presently very scarce. Many papers describe theoretical scientific advancements of WSN, but successful practical introduction of WSN in horticulture needs the input of experiments. The standardization of WSN components, especially the 2.4 GHz broadcast frequency by the Zigbee alliance which is absorbed by water-rich objects, may hinder the introduction of WSN in horticulture. At this point the industry does not produce the "smart dust" that is foreseen for the future of sensors, but rather "smart bricks" which are still expensive and are not yet reliable. Calibration of a T and RH sensor of a greenhouse WSN node shows that it needs radiation shielding to give reliable results. At this moment radio wave propagation tests in a greenhouse do not give conclusive results about the communication distance of a WSN node. However, we have shown that a WSN can be used to measure the T and RH at 100 points within a relatively large greenhouse.

ACKNOWLEDGEMENTS

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Tables

Table 1. Results from a literature database enquiry.

Search query > / Database	sensor network*	"sensor network*"	"sensor network*" horticultur*	"sensor network*" agricultur*
Biological abstracts	119	119	0	0
CAB Abstracts (SP)	36	36	0	0
Google Scholar	859000	26100	12	1120
JSTOR	1376	9	0	0
OAIster	2705	2705	0	0
ScienceDirect (Elsevier)	1505	1505	0	1
SCIRUS (Elsevier)	479801	491	1	23
SCOPUS (Elsevier)	14161	14161	0	0
Web of Science (ISI)	6104	2476	1	11
AGRICOLA (SP)	16	16	0	0
AGRIS (SP)	3	3	0	0
Theses & Dissertations Catalog	56	0	0	0

Figures

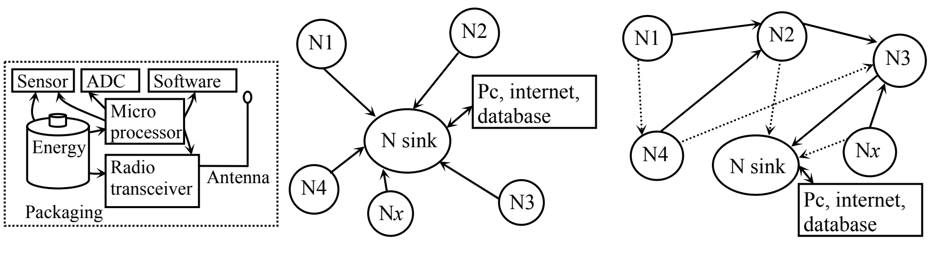


Fig. 1. Common parts of a WSN and their connecting relations (left). Star (middle) and a mesh type network (right).

Fig. 2. Wisensys node (left) and the base station (middle). Wisensys node accuracy test in comparison with other sensor nodes in a climate chamber (right).

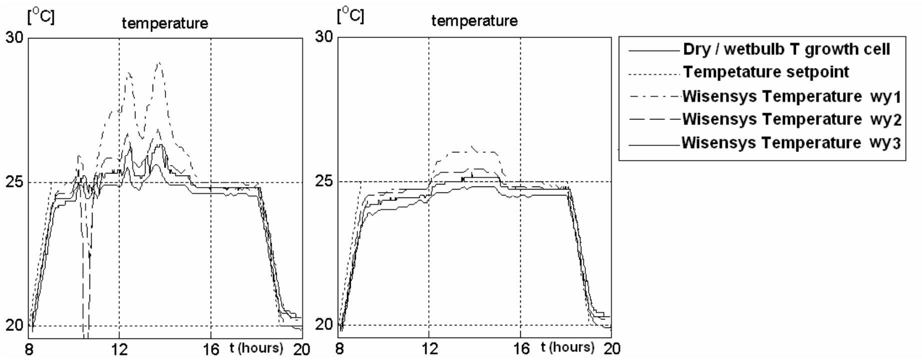
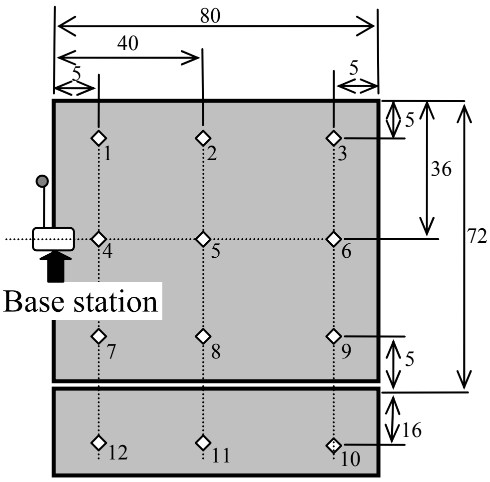


Fig. 3. Results from the first comparison test (left; influence of direct sun radiation) and second test (right; protection against direct radiation), at which the difference between the Wisensys and the other sensors are highlighted with a circle.



Node	Distance to base station [m]	Transmittance success rate [%]
1	32	98.1
2	51	98.1
3	75.2	45.2
4	5	100.0
5	40	99.2
6	75	31.3
7	32	100.0
8	51	95.4
9	75.2	11.6
10	91.2	35.5
11	65.6	90.7
12	52.3	91.9

Fig. 4. WSN node location in a tomato greenhouse (left) and the results of this experiment (right).

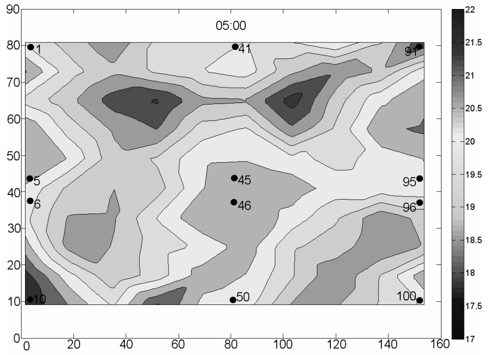


Fig. 5. Contour plot of the temperature distribution measured with 100 sensor nodes and their location show with black dots in a greenhouse with cucumbers at 05:00 30-08-2007. The colour indicates the temperature, the X an Y bars the distance (m).